Quantum Design – a Brief History of a Company Successful in Superconductivity

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***Abstract* – Quantum Design was established in 1982 to design and develop cryogenic and SQUID-based instruments for researchers in physics and materials science. Since then Quantum Design has grown to more than 300 employees and is now considered one of the most successful companies working in the field of superconductivity. This brief review traces the history of Quantum Design's development and describes some of the events that shaped the company.**

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I. INTRODUCTION

Nearly one hundred years after of the discovery of superconductivity it is interesting to look back at the efforts to find commercial applications for this amazing technology – and amazing it is. Before Kamerlingh Onnes' remarkable observations on the disappearance of mercury's resistivity in 1911, no one could possibly have imagined any material achieving a condition of truly zero electrical resistivity. Indeed, it would require more than 45 years of intense theoretical study before Bardeen, Cooper and Schriefer would publish their landmark theory of superconductivity in 1957, for which they would receive the 1972 Nobel Prize in Physics.

From the time of Onnes' original discovery there must have been entrepreneurs who dreamed of exploiting this amazing behavior for commercial purposes, but until the 1950's the extremely low temperatures required to achieve the superconducting state in any material effectively eliminated any commercial applications. That situation changed when researchers discovered malleable alloys of niobium-zirconium and niobium-titanium with critical temperatures above 9 Kelvin and upper critical fields exceeding 10 Tesla at 4.2 K. This discovery made it possible to achieve high magnetic fields with superconducting magnets cooled by liquid helium and would lay the foundation for the first successful commercial ventures in superconducting technology.

The Oxford Instrument Company, founded by Sir Martin Wood in 1959, was probably the first company fully devoted to superconducting technology to become highly successful on a long-term basis. The company's original business was to design and manufacture equipment for generating high magnetic fields, and when the new niobium alloys became available a short time later, Oxford Instruments launched a project to develop a high-uniformity superconducting magnet for a Nuclear Magnetic Resonance (NMR) apparatus. Superconducting magnets for NMR spectrometers soon became a solid business, creating a foundation from which the company could further expand. Oxford Instruments would go on to execute a successful public stock offering in 1983, and eventually achieve annual revenues of several hundred million dollars per year.

Eleven years after Oxford Instruments was established, Prof. John Wheatley of the University of California, San Diego, along with several others founded a company called SHE Corporation specializing not in magnets, but in instrumentation for low-temperature physics. (The letters "S", "H", and "E" are pronounced separately and represent the three core competencies of the company: Superconductivity, Helium and Electronics.) With superconducting magnets already commercially available, SHE turned its attention to dilution refrigerators (which can achieve temperatures in the 5-10 millikelvin range) and the highly sensitive magnetic sensors called Superconducting QUantum Interference Devices (SQUIDs).

These two pioneering companies, Oxford Instruments and SHE Corporation, laid the foundation for most of the later development of commercial superconducting products. Companies such as Intermagnetics General, Bruker and others would follow in the footsteps of Oxford Instruments to build successful businesses in superconducting magnets for NMR and Magnetic Resonance Imaging (MRI) systems. Meanwhile SHE Corporation would be the first to commercialize superconducting research instruments and would become the birthplace of Quantum Design. Today, aside from the NMR and MRI magnet companies, Oxford Instruments and Quantum Design are arguably the most successful commercial enterprises involved in superconducting technology, but both are no longer limited to it. In the rest of this article, I will present a brief history of Quantum Design, and try to describe the company's philosophy and some of the reasons for our success.

II. SHE – THE MEETING GROUND

Established in 1970, over the next 10 years SHE Corporation would pioneer the conversion of SQUIDs and dilution refrigerators from laboratory curiosities into commercially available tools. Prior to the existence of SHE, researchers who wanted to use a SQUID or dilution refrigerator had to launch their own research project to first develop the tool – projects which could literally take years to accomplish. SHE's development of commercial versions of these instruments meant that researchers could now simply buy these products for use in their own laboratories. SHE also developed the first commercial 3-axis SQUID magnetometers for geomagnetic research and the first SQUID systems designed for use in neuromagnetometry (the measurement of the magnetic fields produced by neural currents in living organisms). The company also developed the first commercial variable-temperature, variable-field SQUID-based sample magnetometer, which they called the Variable Temperature Susceptometer (VTS). This instrument used a SQUID to measure the magnetic properties of small samples over a wide range of temperature and magnetic field.

In addition to developing these products, SHE also provided the meeting ground for the four founders of Quantum Design. David Cox, Michael Simmonds, Barry Lindgren and I joined SHE one at a time from 1973 to 1979. While working at SHE we enjoyed the technology we were developing and we also enjoyed working in a small-company environment. So why would we leave such good positions to form a high-risk start up company having no products, no research contracts and funded with just $8,000?

I will have more to say about this below, but the answer is simple – at the time we left, SHE was only a step away from bankruptcy. By early 1981 the company had over 100 employees, with only about $3.6 million in revenue. Even accounting for inflation, anyone the least familiar with operating a business will recognize that the company was overstaffed by nearly a factor of three. As a consequence, morale in the company was terrible. On payday employees joked about racing to the bank to deposit their paychecks, the company's payables were more than 100 days past due, and few vendors in California would ship anything to the company. In response to the situation, Barry and Mike resigned in late 1981, and when it became clear in early 1982 that I was powerless to bring about any change, I too, decided to resign. At this point Mike and I began to discuss doing something on our own. While leading the SHE research group, Mike and I had brought significant outside funding into the company, and Mike suggested that we could do the same in our own company. Shortly thereafter we recruited Barry and Dave and Quantum Design was born. Figure 1 is a photograph of the four founders of Quantum Design taken at about that time.

Fig. 1. The Founders of Quantum Design circa 1982. Rear (From Left): David Cox, Michael Simmonds, Ronald Sager. Front: Barry Lindgren.

III. THE FORMATION OF QUANTUM DESIGN

After leaving SHE, Mike had started his own consulting company, and just as we were talking about launching Quantum Design, two different research projects came to his attention. One involved using SQUID magnetometers to map fractures in gas wells, and the other was a project to design a SQUID detector for magnetic monopoles. The magnetic monopole detector project was prompted by a report from Stanford University of an "event" in a SQUID detection system that was "consistent" with a magnetic monopole having passed through a SQUID detector system [1]. By the time Quantum Design was born on April 12, 1982, Mike had secured both projects for the newly formed company, and with these in hand we jumped off the diving board – hoping the water in the pool was deep enough!

The truth is that without the disastrous conditions at SHE at that time, Quantum Design probably would never have come into existence, but from this experience we learned one of our most important lessons: keep the company financially strong!! We had seen the miserable working conditions created when a company is in severe financial trouble, and we wanted no part of such an environment. Beyond that our goals were to: 1) create a good place for everyone to work; 2) develop high quality instruments based on interesting technology; 3) be responsive to our customers; and 4) run the company with common sense. These principles are now enshrined in a document we call the Basic Values of Quantum Design which is posted prominently throughout the company. Running the company with financial responsibility is, of course, a prerequisite for achieving these goals.

IV. THE FLAGSHIP PRODUCT – THE MPMS

If there is any product that has seemed to define Quantum Design it would have to be our Magnetic Property Measurement System (MPMS). In fact, we have at times struggled against the idea that Quantum Design is a "SQUID company." When our Physical Property Measurement System (PPMS) was introduced in 1992, the question we most often had to answer was "Where's the SQUID?" The MPMS was born in the summer of 1982 while Mike was in the hospital recovering from major surgery. For several days he had nothing to do but think, and during my afternoon visits to his hospital room he described his ideas for an instrument that could be the next-generation successor to the SHE VTS. Mike had worked on the latest version of the SHE instrument, knew all of its problems and during his hospital stay had developed a design that (we thought) would address all of the VTS' weaknesses. With Mike's preliminary design in hand, I visited several of my physicist colleagues, lined up at least one potential customer and we had what we needed.

After Mike's release from the hospital, we set about building the prototype instrument, and perhaps not surprisingly, some of our initial ideas utterly failed. Not to be discouraged, we redesigned the system and built up our first full prototype instrument with a temperature control module, a 2-Tesla magnet and the SQUID detection system. We finally got this system operational about midnight on an evening in early 1983 and began characterizing it. After measuring its noise performance at zero magnetic field, we were encouraged to find that it met our design specification. Then we charged the magnet to its 2-Tesla design field – and the subsequent noise measurement on the SQUID detection system (at about 2:00am) was a disaster. The noise was 10,000 times larger than our expected performance!!

After several days of teeth grinding effort (between discussions in which the phrase "maybe we should just quit now" was uttered more than once) we discovered additional design flaws, but we also found that virtually every single material we had used in the instrument was highly paramagnetic at low temperatures. Interestingly enough, this included several materials I had used in John Wheatley's laboratory that we had believed to be "magnetically clean." This discovery gave us new hope. Flawed as it was, our initial prototype was adequate to characterize the materials we were using and after several weeks of investigation, we had found materials with suitable magnetic properties and began rebuilding the prototype, correcting the design flaws and using the new materials we had identified.

Eventually, of course, we achieved the promised specification and developed the suite of electronics and software required to automate the temperature, magnetic field and measurement control. This very first MPMS, shown in Figure 2, was shipped to Prof. Robert Shelton at Iowa State University in July of 1984. The success of this instrument generated substantial customer interest in the new Quantum Design technology, but SHE was still manufacturing its VTS, and we immediately found ourselves in a competitive situation. The customers for a SQUID magnetometer clearly wanted a magnetic field capability of at least 5 Tesla, so almost literally from the day we shipped our first instrument, we began a major redesign to accommodate the higher magnetic field and improve the instrument's electronic configuration.

Fig. 2. The Mark I – the first Quantum Design MPMS. This 2-Tesla MPMS used an SHE Model 30 SQUID controller and the user interface was written in BASIC on a Hewlett-Packard HP-85 computer. The system was shipped to Prof. Robert Shelton at Iowa State University in July 1984.

This effort took more than a year, culminating in what would become our standard 5.5-Tesla MPMS, the first of which was shipped in December 1985 to Prof. Allen Goldman at the University of Minnesota. (This instrument is still running today in Prof. Goldman's laboratory.) Over the next year the MPMS captured the market for SQUID magnetometers and this, combined with SHE's growing interest in neuromagnetometry, led to their announcement in mid-1986 that they would no longer offer the VTS for sale. At that point, Quantum Design was the only company in the world manufacturing a SQUID magnetometer system – and was poised for the breakthrough that would shake the world of superconductivity.

V. THE HIGH-TEMPERATURE SUPERCONDUCTOR EXPLOSION

Just weeks before SHE withdrew their VTS from the market, Bednorz and Müller had published their seminal paper on the discovery of a perovskite-based material which displayed superconductivity at the unheard of temperature of 35 K [2]. At the time of this discovery, existing theories predicted that superconductivity could not occur above temperatures of about 30K. After being initially somewhat overlooked, the discovery was finally verified by other researchers and by December of 1986 Bednorz and Müller's astonishing discovery was generating frenzied research activity in low-temperature physics laboratories around the world, culminating in the 1987 March meeting of the American Physical Society (APS). At this meeting, Prof. Brian Maple of the University of California, San Diego chaired a special evening session that continued past 3:00 am, in which some 50 papers on the new high-temperature superconducting (HTS) materials were presented. This event would quickly become known as the "Woodstock of Physics". By the time of this meeting not only had the original discovery been confirmed, but the highest temperature at which the new HTS materials displayed superconductivity had been pushed to over 90K [3].

Because superconductivity is intimately related to the magnetic behavior, a SQUID-based magnetometer was the perfect instrument for studying the HTS materials. Nonetheless, at the time of the March 1987 APS meeting the new discovery had produced little impact on Quantum Design. When the original paper was published in mid-1986 we had shipped only four of our 5.5-Tesla MPMS instruments and had accepted orders for an additional three systems. By March 1987 we had still shipped only 8 units with 6 systems on order – barely a hint of the tidal wave to come.

After the March 1987 APS meeting we began receiving an increasing number of inquiries and orders for the MPMS, most notably from Japan where the first two MPMS systems were installed in August 1987 - in research laboratories operated by Nippon Telephone and Telegraph (NTT). Interest in the MPMS continued to grow through the latter part of the year until by the end of 1987 we had shipped 15 systems and had roughly another 15 on our backlog. From today's perspective these numbers seem small but for a company of fewer than twenty employees this represented a substantial level of business, especially considering that December 1987 was the first month in which we ever shipped more than one MPMS. Nonetheless, by the end of that month we had promised to ship twelve MPMS systems by March 22, 1988, which would just meet the funding deadlines of our Japanese customers. The leading edge of the tidal wave had finally struck but the full tidal surge was still roaring toward us.

Fortunately, before the demand for the MPMS began to grow we had done our homework by laying a solid foundation for larger scale manufacturing. At this point we had a fairly complete documentation package for the MPMS, which included assembly drawings, parts lists and descriptions, purchasing reports and check lists for calibrating and testing the instruments. When the demand began to grow, this foundation allowed us to hire new people and quickly train them to build and test the instruments, leaving the rest of us free to do further development. The necessity for laying this crucial foundation for manufacturing is often overlooked in small startup companies.

I remember the period of January to March 1988 as being similar to my graduate school years – an endless series of 16-18 hour workdays, 7-days a week, going on month after month. In the end the hard work paid off when we shipped the last 5 systems to Japan all on one day – March 22, 1988. By this time we had increased our rate of production, improved our purchasing process, and established well-defined calibration and test procedures for the instruments. Then the tidal wave rolled over us. In spite of shipping 12 instruments from January through March, during that period our backlog had grown to nearly 20 instruments (roughly $2 million), and we were quoting delivery times of 5 months after receiving an order. Then through April, May and June our backlog skyrocketed to more than $6 million and our promised delivery times stretched out to more than 15 months. We simply couldn't ramp up our production process fast enough to handle such a huge and sudden increase in demand!

This flood of orders led to explosive revenue growth: from $1.3 million in 1987, to $5.5 million in 1988 and $9.9 million in 1989. At this point we managed to avoid a mistake made all too often by companies in similar situations – overextending the company financially on the assumption that the revenue growth in 1990 would continue on the same curve as the previous three years. Conversely, we were expecting the buying frenzy to subside and, indeed, by the end of 1989 the rate of discovery had slowed down and the research community had settled down to the arduous task of understanding the mechanisms which produced superconductivity at such unexpectedly high temperatures.

Another development in the SQUID instrumentation market at this time also gave us significant concern. Our extremely long delivery schedules in 1988-1989 left many customers waiting over a year to get their instrument and this pent up demand provided a wonderful incentive for other companies to develop competing instruments. In late 1988 a Japanese company by the name of Hoxan introduced a near clone of the original SHE VTS instrument and sold a number of them in Japan. Shortly thereafter Cryogenic Consultants Limited (CCL), a UK-based company, introduced their own SQUID magnetometer, and a new startup company in France named Metronique introduced a new 8-Tesla SQUID magnetometer system. At about the same time Lakeshore Cryotronics (located in Westerville, Ohio) introduced an AC magnetometer system which would later be upgraded to include a DC magnetization capability to become their Model 7000 AC-DC Magnetometer system. All of these instruments were direct competitors for the Quantum Design MPMS.

As the buying frenzy from the HTS discovery subsided, competitors began capturing market share, our revenue dropped to about $7.3 million in 1990 and we realized that Quantum Design had a significant vulnerability. We were a one-product company, and our market was being eroded by both competition and decreasing demand for our only major instrument. Consequently, we began to look for a way to fill the gap left by declining sales of the MPMS. This led us into two new ventures; one in form of a new product and the other in form of a new company.

VI. WHAT DO WE DO NOW?

In 1986 we had made the acquaintance of Prof. Lowell Burnett, the chairman of the physics department at San Diego State University (SDSU). Lowell's background was Nuclear Magnetic Resonance (NMR) and he had been very successful at bringing research grant money into the SDSU physics department. We teamed up with Lowell in 1987 to form a new company, Quantum Magnetics, which was supposed to perform externally funded research that would lead to new products that Quantum Design would then manufacture. The research in Quantum Magnetics would be funded by Quantum Design as well as by research grants from various government agencies under the Small Business Innovative Research (SBIR) program.

Quantum Magnetics was set up with Lowell as its president while Mike Simmonds and I became its two senior research physicists. With funding from Quantum Design to develop new products and Lowell's ability to write successful research proposals, Quantum Magnetics began hiring additional physicists and expanding its research activities. This relationship between Quantum Design and Quantum Magnetics would continue until 1994.

In the meantime, as demand for the MPMS declined, a question often asked in our internal discussions was, "How are we ever going to repeat the success of the MPMS?" In fact, the MPMS provided the seeds for its own successor. At about this time we began to receive requests for an "MPMS without the SQUID." Many MPMS customers liked the instrument's automated temperature and magnetic field control and some wanted to use it as a basic temperature and magnetic field platform for their own measurements. Recognizing that the small MPMS sample chamber would severely restrict any such use, we developed a design for a new instrument with a much larger sample chamber, which would eventually become the PPMS.

When several MPMS owners said they would definitely pursue funding to purchase such an instrument, we launched a research program to develop it, and our first PPMS was delivered to Purdue University in February of 1994. Figure 3 shows one of our early PPMS systems. But the marketplace is never static and even before we delivered our first unit to Purdue, Oxford Instruments announced a competing product which they called the MagLab. Oxford apparently viewed our PPMS as a challenge to their standard magnet systems which were often supplied with a variable-temperature insert. The competition between the Quantum Design PPMS and the Oxford MagLab would continue until 2001, when the MagLab was withdrawn from the market.

While originally conceived as an automated temperature and magnetic field platform for which researchers would design their own measurement apparatus, we realized that we could also develop measurement capabilities for the platform. We didn't yet realize, however, that our customers would demand that we do so – and that the demand would be immediate. While the first PPMS had no measurement options at all, the very next customer wanted to measure AC and DC magnetization and he wanted Quantum Design to provide the hardware and software to perform the measurements. This launched our effort to develop measurement options for the PPMS – an effort that continues to the present time.

Development work on further PPMS options was motivated by a marketing study which clearly showed that the long-term success of the PPMS system would be directly proportional to the number and types of measurement capabilities we could provide to the customer. Our experience of the last 15 years has validated that conclusion. Very few PPMS instruments have ever been delivered without several measurement options, and our sales of these instruments have grown steadily as we have introduced more and more measurement capabilities.

Fig. 3. An early PPMS system. This instrument is shown with the sample drive mechanism (on the top of the dewar and probe assembly) that provides the sample motion for the PPMS AC-DC Magnetization (ACMS) measurement option.

While developing the new PPMS system we also managed to fight off most of the competition for our MPMS. Hoxan had stopped offering their VTS clone, Metronique had failed, CCL had declared bankruptcy (to be reformed by its original owner under a new name), and we were rapidly winning the competition against Lakeshore. However, this situation wouldn't last for long and by 1995 the MPMS was once again facing competition – this time from Conductus.

Conductus was one of the highly-funded startup companies formed to develop commercial products based on the new HTS materials. By 1995 Conductus was manufacturing niobium SQUIDs and had bought Tristan Corporation, a small cryogenic instrument company in San Diego, which they renamed the Conductus Instrument and Systems Division (CISD). CISD's charter was to develop a line of superconducting products for their parent company, and in 1995 CISD launched their ChiMag system, a SQUID magnetometer specifically designed to capture the MPMS market. Indeed, within a few months of its introduction, Conductus had received six orders for the ChiMag from Japan – a direct thrust at one of our most important markets. When we learned of CISD's plan (well before the ChiMag was announced publicly), we immediately launched a program to modernize the MPMS and by the APS meeting in March of 1996 we were ready to introduce our new MPMS-XL. This updated version of the MPMS, with its Continuous Low-Temperature Control (CLTC) and Reciprocating Sample Option (RSO), was a direct response to the challenge from Conductus.

The competition with Conductus didn't last long. After accepting the six Japanese orders and a seventh from an American institution, Conductus was nearly a year late with their deliveries and the ChiMag failed to meet the customers' expectations. By early 1997 it had become clear that the ChiMag was not a viable competitor and by late 1997 Conductus had shut down CISD and sold off its assets.

Fig. 4. The MPMS-XL, with the new Continuous Low Temperature Control and Reciprocating Sample Option, was first displayed at the APS meeting in March 1996.

VII. THE TRANSITION YEARS

In retrospect it is easy to see that the late 1990's were a major transition period for Quantum Design. The first major event occurred in 1994 when Quantum Design and Quantum Magnetics agreed to separate. During the early 1990's Quantum Magnetics had taken an increasingly independent path in its research activities, losing its emphasis on doing research that would lead to products for Quantum Design. The two companies officially separated on April 15, 1994. Quantum Magnetics, which had begun working on explosives detection for airport security, was subsequently bought by InVision Technologies on September 30, 1997, and after the World Trade Center disaster, InVision was acquired by General Electric in December 2004.

With the departure of Quantum Magnetics, Mike Simmonds and I rejoined Quantum Design and began rebuilding Quantum Design's product development group, which would now be focused exclusively on developing new products. By late 1996 this effort had culminated in the Heat Capacity Option for the PPMS and the new MPMS-XL described above.

In mid-1996 we experienced another major transition when Barry Lindgren, our President, CEO, Chairman of the Board and one of the four original founders of Quantum Design decided to leave the company. When Barry resigned his position in July 1996, we asked Jerry Daviess to take over as President while I became the CEO and Chairman of the Board, roles that we continue to fill today. Jerry had joined Quantum Design in 1995 to lead our sales and marketing effort, and with his Executive MBA degree and experience selling Computed Tomography X-Ray systems for GE and Toshiba, he brought significant outside experience to the Quantum Design executive team.

Two months after Barry's departure the company finished its 1996 fiscal year with just over $8 million in revenue (and a very marginal profit of just $80,000), but with several new products just entering the market we were poised for substantial growth. By the end of 1996 we were selling the MPMS-XL and the PPMS Heat Capacity Option, both of which gave an immediate boost to our sales. Additional new products introduced in 1998-1999 and our new subsidiary in Japan added enough additional revenue to take us to $21.5 million by fiscal 2000. This was an average compounded growth rate of 28%

per year from 1997 through 2000 – but such rapid growth brought with it a new and completely different set of problems.

By the end of 2000, we were struggling with a decline in the quality of our products, an inability to install a working system in the customer's laboratory and a failure to solve customer service problems in a timely manner. Internally, our material control function was breaking down under the increased material flow, many test procedures were being ignored or bypassed, and we had literally hundreds of unfinished engineering change orders pending against parts that were currently in inventory and even being used in production.

In earlier years more than 90% of our installations in customers' laboratories were successfully completed in 2-3 days, including the time needed to train the customer to use the instrument. By the end of 2000 less than one-third of our installations were successful on the first attempt and some installations required as many as three trips to the customer's lab to get the system working properly. The increased production demands were overwhelming our material handling, quality control, assembly and final test functions, and the breakdown was having a noticeable and very negative impact on our customers – who weren't shy about expressing their displeasure!

When it became clear that the existing management team didn't know how to reorganize the operation and build the necessary infrastructure to handle our growth, we concluded that a major reorganization of the company was our only hope for correcting the problems. We undertook this reorganization early in 2001. The first step was to fully implement our automated Material Resource Planning (MRP) system which we had bought in 1995 but was still only about 10% implemented. This took nearly a year, but when it was fully implemented our material control problem was finally solved.

During the same period we implemented major changes in the company's management team. In 2001 we hired a new Chief Operating Officer to organize our overloaded production process, and then in early 2002 we replaced the managers of our production, material control and engineering departments. While such actions may sound draconian, the company was collapsing under the weight of its own success and our management team didn't know what to do. The results speak for themselves. In fiscal 2001 our San Diego operation shipped just over $14 million in products, but our production and test personnel were working huge amounts of overtime and people were at the company all hours of the day and night to get the products out the door. A year later, with only about a 20% increase in our production staff, the same operation shipped $19.6 million with minimal overtime and regular working hours – a whopping 40% increase in output with dramatically reduced working hours and a nominal increase in production personnel. This was a startling demonstration of just how much a well organized manufacturing process can increase a company's efficiency.

Since that transition period, Quantum Design has recovered its direction, as our recent business and financial performance attest. It is worth noting, however, that the difficulties we encountered are not at all unique or unknown. The problems encountered when entrepreneurial companies outgrow the founders' ability to directly manage every aspect of the company are well known and are discussed in many books and articles. I can recommend two excellent books that discuss this process: "Thriving on Chaos" by Thomas Peters, and "Corporate Life Cycles" by Ichak Adizes [4,5]. These books discuss the fine line a company must walk in making such a transition – between crippling the company, because the management team is inadequate and crippling the company with an overly expensive and bureaucratic management structure.

In retrospect, I believe we avoided both of these traps at Quantum Design. By the end of 2002 we had hired a competent management team and positioned the company for its next stage of expansion, which would take three simultaneous and somewhat different paths: a large R&D effort to develop new lines of cryogenic products, a steady expansion of our distribution business and the development of a completely new type of medical diagnostic product.

VIII. NEW PRODUCT DEVELOPMENT

While Quantum Design maintained a strong product development effort throughout the 1990's, most of our work during that period was devoted to expanding the capabilities of our MPMS and PPMS product lines in response to customer requests and competitive challenges. This effort culminated in 1997-1999 when we developed and launched the EverCool option for the MPMS and PPMS. These projects were motivated by two Japanese companies which had just introduced small helium liquefiers dedicated to a single MPMS or PPMS. The EverCool dewar (cryostat), shown in Figure 5, is designed to eliminate the need for liquid helium after an initial liquid transfer to cool the system down from room temperature [5]. With the other development efforts described earlier, these projects kept our R&D staff fully occupied during the 1990's.

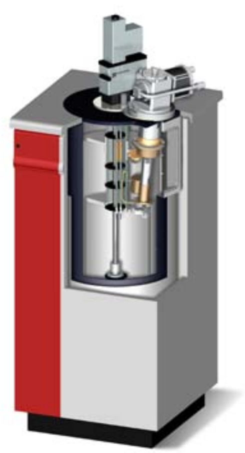

Fig. 5. The MPMS EverCool dewar and cabinet assembly. The 1st stage of the cryocooler is attached to the thermal shields in the dewar, while the second stage recondenses the helium gas that would otherwise be lost.

By the late 1990's we had clearly won the competitive battles in the MPMS market, but the PPMS was still competing with the Oxford Instruments MagLab and high-field VSM (vibrating sample magnetometer) product lines. Virtually every PPMS order involved some level of competitive bidding. While we successfully captured a large majority of the orders and our revenues were still growing, it was also clear that we needed to develop further new options for the PPMS, a new SQUID-based measurement platform, and a more modern suite of electronics. This would require a multi-year, multi-million dollar investment.

We chose a SQUID-VSM as the ultimate goal of this effort and began the development work in 2002. Since it was clear from the beginning that the success of the project would depend on eliminating vibrations from the sample drive mechanism, Mike started with the linear motor design. It was also clear that designing a VSM option for the PPMS would be a much easier task than designing the full SQUID VSM. So with assurances from our sales team that there would be significant demand for the product, we used the PPMS VSM to lay the foundation of our new electronic architecture.

When that project was completed with our first PPMS VSM shipment in August of 2003, we resumed work on the SQUID VSM. Fulfilling our expectation of its difficulty, this project took another 3 years to complete, but the new SQUID VSM was finally introduced in March of 2006 and the first instrument was shipped the following June.

In parallel with the two VSM development projects, we also began to explore designs for instruments that would eliminate the need for liquid cryogens. With the invention and commercial availability of the new cryocoolers (employing regenerators based on magnetic materials such as erbium, erbium-nickel, holmium and holmium-copper) it became possible to design cryogenic measurement systems in which the magnet, temperature control and detection systems are all cooled by thermal conduction using the cryocooler as the heat sink.

This technology is now widely used by companies that manufacture cryogenic equipment, and at Quantum Design we used it first in the VersaLab. The VersaLab employs a 0.1 watt cryocooler to cool a 3-Tesla magnet and operate a temperature control system over the range of 50-400 Kelvin (extensible to 1,000 Kelvin using the oven option). The VersaLab serves geographic markets where liquid helium is either not available or prohibitively expensive, as well as the general VSM market where rapid measurements of hysteresis loops are needed and a 3-Tesla magnetic field is adequate.

The DynaCool is our latest entry in cryogen-free technology. This instrument, introduced at the March 2009 APS meeting, is designed to provide performance comparable to our standard PPMS in a cryogen-free system. Some readers may recall that Quantum Design first displayed an instrument of this type at the March APS meeting in 1998. That instrument was a test bed to evaluate and understand the problems in developing a cryogen-free PPMS, but the project was suspended later that year when we launched the EverCool project. The DynaCool project was reactivated in 2007 under the present development effort, and the first DynaCool delivery is scheduled for early 2010.

IX. THE GLOBAL DISTRIBUTION NETWORK

When SHE discontinued their VTS SQUID magnetometer in 1986, their Japanese distributor, Niki Glass Corporation, was eager to sell our MPMS in Japan and we gratefully accepted their offer. However, by 1994 we were having serious problems with customer service in Japan, a market that accounted for nearly 50% of our revenue at that time. With Niki Glass unwilling to provide the necessary support for our service needs, in 1994 we switched to a different distributor, but in spite of strong technical support from San Diego, the new distributor was only marginally better. Our continuing difficulty with service in this important market eventually led us to establish Quantum Design Japan (QD-Japan) in July 1997. While the immediate purpose of QD-Japan was to sell Quantum Design's products and solve our service problems, we intended from the very beginning that the company would eventually expand its activities to sell other company's products as well. QD-Japan was an immediate success, and by 2000 the company was contributing over $8 million/year to our consolidated revenue.

In fairness to our foreign distributors I should point out that distribution companies make their money by selling products – not by providing after-sales service and support. Therefore they almost uniformly see the costs associated with such service as a financial drain on their sales organization. On the other hand many manufacturers, Quantum Design in particular, view their after-sales service and applications support as essential parts of their sales strategy. This is a rather common point of contention between manufacturers and their foreign sales representatives.

Our success in Japan suggested that a similar approach might work in other markets, and we subsequently opened Quantum Design Korea in 2003 and Quantum Design China in 2004. QD-Korea was established as a branch office of QD-Japan, and QD-China was formed as a Chinese company (officially, a Wholly-Owned Foreign Enterprise) owned by Quantum Design San Diego. All 3 companies have actively solicited distribution rights for products from other companies and collectively they now sell products for approximately 25 other manufacturers.

Europe was the next obvious extension of our distribution network and we began negotiations with our European distributor, LOT-Oriel, in July 2004. In a stroke of good timing, the owners of LOT were all reaching retirement age, and within a few months Quantum Design and LOT had formed a Strategic Alliance linking LOT into our distribution network. The agreement also specifically identified a merger of the two companies as a possible long range goal. The Strategic Alliance was successful and by November 2007 the two companies had agreed on terms and executed an agreement under which Quantum Design acquired a majority ownership in LOT.

The impact of the distribution system on our business performance can be seen by looking at the consolidated revenue of the collective companies. As shown in Figure 6, since 1996 our annual revenue has grown from $8 million to just over $102 million, nearly two-thirds of which is now being generated by our distribution network.

The most recent additions to our distribution system are still in the early stages of development. Quantum Design India, established in 2009 to serve our growing sales in that country, is just now becoming an active member of the global network. India is widely viewed as an emerging market and we expect QD-India to expand rapidly. Quantum Design South America, which will be located in Campinas, Brazil (near Sao Paulo), will open in early 2010 and will handle the entire South American market, particularly the emerging market in Brazil. As with our other distribution centers, both QD-India and QD-South America will be general distribution companies, selling and servicing products for Quantum Design as well as other companies.

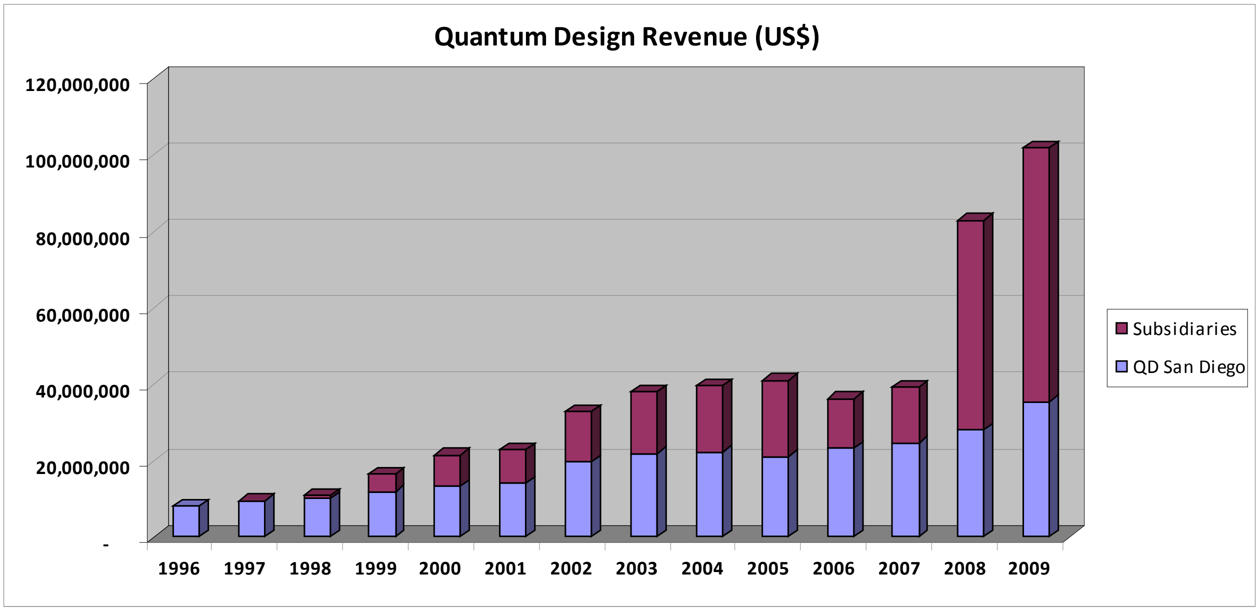

Fig. 6. Quantum Design revenue since 1996 showing relative revenues of Quantum Design San Diego and its distribution subsidiaries.

X. A MEDICAL DIAGNOSTIC PRODUCT

The third development project that Quantum Design undertook in the late 1990's was a long-term project to develop a new medical diagnostic device, which we now call the Magnetic Immuno-Chromatographic Test (MICT) system. This work grew out of our knowledge of magnetic measurement techniques and a desire to diversify Quantum Design beyond the niche market of superconducting instrumentation. In an unexpectedly long development program, we have developed the magnetic detection system for this new class of diagnostic tests as well as the biochemistry associated with the tests. This project is just coming to fruition under a Quantum Design subsidiary formed in 2003 called MagnaBioSciences (MBS). As of this date MBS is test marketing its first products in the human diagnostic and food testing markets, and we expect to achieve substantial revenue growth in this business over the next two years.

XI. KEYS TO SUCCESS

I am sometimes asked why Quantum Design has been so successful – and yes, I think it's fair to say that we have been successful. Starting with an initial capital investment of only $8,000 (and without raising any external investment capital), in 27 years of operation we have posted a profit in every year but one. Our single loss occurred in 1992 when our revenues dropped almost 30% from the previous year, and even then we managed to keep the loss to only a few percent of revenue. It is safe to say that our financial discipline was instilled in us by our experience at SHE Corporation where the lack of financial responsibility destroyed the working environment of the company.

Clearly our top priority is keeping Quantum Design financially strong. This has allowed us to pursue new opportunities as they arise, such as launching new research projects, setting up foreign distribution offices and pursuing other projects which offer long-term growth and diversity. These all require cash. A company which is constantly struggling to meet its payroll doesn't have the financial resources to pursue long-term opportunities. This is why companies that create middle management bureaucracies often fail. The cash flow required by their excessive and often highly-paid middle management not only prevents them from taking on new development projects, it cripples their ability to stay price competitive with their leaner competitors. In addition, the bureaucracy often stifles the company's technical creativity. By keeping Quantum Design financially strong and free from bureaucracy we have been able to pursue opportunities as they present themselves, most notably perhaps our acquisition of LOT. Without Quantum Design's well established history of financial strength that acquisition would have been impossible.

The second key element of our success has been our consistent ability to create products that perform useful measurements for researchers, that are easy and convenient to use, and above all, that work as promised. Our success in this regard is a testimonial to our research team at Quantum Design, still led primarily by Mike Simmonds. Under Mike's leadership, Quantum Design has consistently designed advanced measurement systems with fully integrated hardware and software that work to their stated specifications. That's not to imply, however, that every system we install works perfectly the first time it is turned on. Our instruments involve extremely complex technology and they can fail in more ways than one can imagine – and often do!

This is one of the reasons we do not normally purchase products from other companies or have outside engineering firms develop products for us. There is simply no substitute for having your own product development team grind through and solve the myriad problems encountered when developing one of these instruments. When the instrument finally reaches the market, the in-house research team has the knowledge and experience to identify and solve the inevitable problems that arise when a newly designed instrument is placed in a customer's laboratory. Buying products from someone else, or having someone else develop products for you, deprives your in-house team of that invaluable experience and makes your customer service function much harder.

Our strong commitment to customer service and applications support has been another important element of our success. We have repeatedly seen the importance of having a responsive and capable service and applications staff; indeed, this issue was a deciding factor in our decision to establish our own distribution and service centers. In every case we were able to quickly resolve our pending service problems – and our sales increased as soon as we did so. This principle has become one of the defining elements of our global distribution system, which is part of what sets our distribution network apart from nearly all other foreign sales organizations.

As I described previously, Quantum Design went through a period where our product quality and customer service noticeably deteriorated because of our internal organizational problems. In the last 8 years we have worked extremely hard to correct those problems and improve not only our technology, but also the reliability of our products and our customer service. In the end, however, our opinion doesn't matter – the only thing that does matter is our customers' opinion, and they will issue the final verdict by determining our success or failure in a competitive environment.

I have also been asked why Oxford Instruments and Quantum Design have achieved notable success while other companies in the superconducting instrumentation business have been unable to break out of their smaller niches. The road to success for the two companies was perhaps not so different. Shortly after being established, Oxford Instruments seized an opportunity to develop a new high-uniformity superconducting magnet for an NMR application and turned that into a solid business by becoming the first company to address that important market. This foundation gave the company a solid financial base, from which to expand, and they went on to develop many other products: other cryogenic products, medical electronics, general analytical instruments and eventually large-scale superconducting magnets for Magnetic Resonance Imaging (MRI) systems.

In contrast, Quantum Design was formed in 1982, well after Oxford, and a number of other cryogenic equipment companies were already in business. Mike Simmonds and I both had experience designing and using SQUID detection systems and, as I recounted above, we believed that our MPMS could replace the SHE VTS as the premier SQUID magnetometer. Within a year after we introduced the MPMS it had done so, leaving Quantum Design with its first major product in an otherwise unoccupied niche.

Clearly we had the extremely good fortune of being the only company in the world building such an instrument when the HTS discovery was announced and in that respect, Quantum Design and Oxford Instruments are somewhat similar. Oxford was in exactly the right place with exactly the right technology to exploit the rapid growth in superconducting NMR magnets in the 1960's; Quantum Design was in a similar position with its MPMS when the HTS materials were discovered. Both companies then used the resulting business and financial foundation to expand their suite of cryogenic products and later extend their businesses in other directions.

The question of why other companies have been unable to duplicate the success of Oxford Instruments and Quantum Design is complex, but there may be some common factors. First, the very existence of two major players in such a niche market makes it difficult for smaller companies to grow substantially. Any significant opportunity will immediately draw the attention of one of the bigger players, who can bring much greater resources to bear on the opportunity. Secondly, Oxford Instruments and Quantum Design have historically maintained their competitiveness by offering the customers better technology, instruments that meet promised specifications and better service. These factors were essential elements in our success in the competitive situations I described above, and continue to be important elements of our business strategy.

In the final analysis, the other smaller companies in superconducting and cryogenic technologies have remained small, because they have either made a corporate decision not to grow, have failed to find a vacant niche without strong competition or have pursued business opportunities that have ultimately failed. In the case of SHE Corporation[1], the company chose to pursue biomagnetism, a technology that required financing in excess of $100 million which they raised by selling the company to outside investors. After doing so, they encountered substantial competition from two equally competent although at that time less well funded biomagnetic companies: Neuromag in

[1] Then renamed BTi: Biomagnetic Technologies, Inc., later 4D Neuroimaging.

Helsinki, Finland, and Canadian Thin Films (CTF) in Vancouver, Canada. Neuromag eventually became a formidable competitor when they were bought by Elekta (a large Swedish medical technology company), and SHE's failure to develop its technology into a profitable business finally led its financial backers to withdraw their support.

In conclusion, it is certainly true that both Oxford Instruments and Quantum Design were the beneficiaries of good fortune, but in both companies good fortune was followed by solid business decisions and well-considered research and development efforts that led to viable new products. Also, both companies successfully pursued opportunities outside of their core technology that led to further growth and success. But the business world is a dynamic and unforgiving environment, and the long-term success of any business depends on its continuing ability to make good decisions at the right time. That is true in small companies as well as large ones, and the future success or failure of Quantum Design and all the other companies involved in superconducting technology will depend strongly on the decisions their leaders are making right now.

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